

Rapid Caffeine Monitoring in Coffee Beverages Using a Portable Paper-Based Electrochemical Flow Device

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Abstract

Rapid determination of caffeine is important for beverage quality control, product verification, and regulatory monitoring. However, conventional laboratory-based techniques often require expensive instrumentation and centralized analytical facilities, limiting their suitability for rapid on-site analysis. In this work, a portable paper-based electrochemical flow device was developed for rapid caffeine monitoring in coffee beverages using a pump-free capillary-driven flow system. The disposable platform integrates a laminated paper flow channel with an external wood-cased pencil graphite electrode, while a capillary-coupled flow design passively regulates fluid transport to achieve rapid and reproducible electrochemical detection without external pumping or electrical power. Under the optimized conditions, only 5 μL of sample was required, and each analysis was completed within 35 s, corresponding to a throughput of 103 analyses h^{-1} . The device demonstrated excellent fabrication reproducibility (1.9% RSD), analytical precision (2.8–3.0% RSD), continuous operation for approximately 1 h 40 min, and durability of up to 260 consecutive injections. The method exhibited a linear response for caffeine over the concentration range of 0.5–9.0 mM with a limit of detection of 0.62 mM. The proposed method was successfully applied to the determination of caffeine in commercially available coffee beverages, providing satisfactory agreement with product label information. Owing to its low fabrication cost (approximately USD 0.04 per device), portability, and minimal reagent consumption, the proposed platform offers a practical alternative for point-of-need caffeine monitoring and routine food quality assessment.

Keywords: Caffeine; Coffee beverages; Paper-based electrochemical device; Portable food analysis; Food quality monitoring